Effect of overloading and Band overloading on fatigue crack growth of aluminum alloy 7075-T651

By

Hemant Nautiyal

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by

HEMANT NAUTIYAL

212MM1418

Under the guidance of

Prof. B.B VERMA (MM)

&

Prof. P.K RAY (ME)

Department of Metallurgy and Material Engineering

NIT Rourkela-769008

2014

Certificate

This to certify that the thesis entitled "**Effect of overloading on fatigue crack growth of aluminum alloy 7075-T651"** submitted by **Hemant Nautiyal** for the award of the degree **Master of technology** of NIT Rourkela is a record of bonafide research work carried out by him under our supervision and guidance.

To the best of our knowledge, the work incorporated in this thesis has not been submitted in full or part, to any other university or institute for the award of any other degree or diploma.

Prof. B.B Verma
Department of Metallurgical and Materials Engineering
N I T Rourkela.

Prof. P.K. Ray
Department of Mechanical Engineering
N I T Rourkela.

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Hemant Nautiyal

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Abstract

Present investigation involves the study of fatigue crack growth behavior of thermo-mechanically treated aluminum alloy 7075-T651. The investigation is focused to study the effect of single and multiple loading cycles on crack growth behavior. The test were carried out at stress ratio, R=0.3. The fatigue cracked specimens were subjected to overloading spike or band at a/w=0.35 followed by constant amplitude loading cycles. Significant crack growth rate retardation was noticed for multiple overloads in case of OLRs 1.5 and 1.75. However, there were insignificant retardation in case of overload spikes of 1.25 and 1.5. No sign of retardation were noticed even on application of 10 overload cycles of OLR 1.25. Insignificant retardation in case of OLR=1.25 may be due to low value of maximum stress at the notch tip and corresponding stress intensity factors ΔK(6.14 MPa√m) and K_{max}(6.822 MPa√m). This has resulted monotonic plastic zone size not large enough to retard growing crack. Overload of higher magnitude induce large monotonic plastic zone and therefore the significant retardation is observed. The application of band overload, on the other hand, developed a series of monotonic plastic zone, identical to plastic wake and enhanced the effect of retardation for given value of overload.

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Therefore material can be safely used in structural application subjected to overloading especially aircraft.

Keyword: Fatigue crack growth, overloading, aluminum alloy

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Nomenclature

K	Stress intensity factor
K_{IC}	Plain strain fracture toughness
σ	Stress
Y_1 , Y_2	Geometric factors
b,w	Lateral dimensions
E	Young’s Modulus
γ	Surface energy
A	Area
G	Energy release rate
G_C	Critical strain energy release rate
U_v	Elastic energy stored in a material
c	Crack size
σ_{local}	Stress at crack tip
r	Distance from crack tip
σ_y	Yield strength
r_y	Plastic zone radius
σ_{min}	Minimum stress
σ_{max}	Maximum stress
σ_m	Mean stress
R	Stress ratio
$\Delta\sigma$	Cyclic stress range
σ_a	Cyclic stress amplitude
N	Number of cycles
S	Stress value

a_0	Initial crack size
a_c	Critical crack size
ΔK	Stress intensity factor parameter range
ΔK_{th}	Stress intensity factor parameter threshold range
C,m	Material parameters(constant)
Y	Geometric parameter
K^*	Critical stress intensity factor for crack growth
OLR	Over load ratio
ΔK_{BL}	Stress intensity factor range at base line

Chapter 1

Introduction

1.1 Background

Fracture is the separation, fragmentation of a body into two or more parts under the stress. Fracture can be considered to be made of two components i.e. crack initiation and crack propagation. Fracture are basically of two types: Ductile and Brittle fracture. In ductile fracture an appreciable amount of plastic deformation prior to and during propagation of crack is there. In brittle fracture rapid rate of crack propagation is found with no gross deformation or very less deformation.

Fracture toughness of a material can be define as the ability of a material to absorb energy prior to fracture. Fracture toughness describes the capability of material having a crack and to resist fracture, it is very necessary property of a material to have for various application. The linear-elastic fracture toughness of a material is determined from the stress intensity factor (K) at which a thin crack in the material begins to grow. It is denoted K_{Ic} and has the units of Pa$\sqrt{m}$. Plastic-elastic fracture toughness is denoted by J_{Ic}, with the unit of J/m^2, and is a measure of the energy required to grow a thin crack.

A metal subjected to a repetitive and fluctuating stress will fail at stresses much lower than to cause a fracture on a single application of load. Failure occurred at such dynamic loading conditions are called fatigue failure. Fatigue has become more prevalent as we develop greater amount of equipment. Example- automobile, turbines, other rotary and reciprocatory devices which are subjected to repeated loading and vibration.

Fracture toughness

The fracture toughness, K_{IC}, (units**:** MPa m$^{1/2}$ or MN/m$^{1/2}$) is used to measure resistance to the propagation of the crack offered by the material. A crack is introduced intentionally and the sample is loaded, the length of the crack is 2c or crack of length at surface is c (Figure 1), applied tensile stress σ or the bending load F at which the crack suddenly propagates. The quantity K_{1C} is then calculated, respectively, from

$$K_{1c}=Y_1\sigma\sqrt{\pi c}$$

or $$K_{1c}=Y_2\frac{F}{bW}\sqrt{\pi c}$$

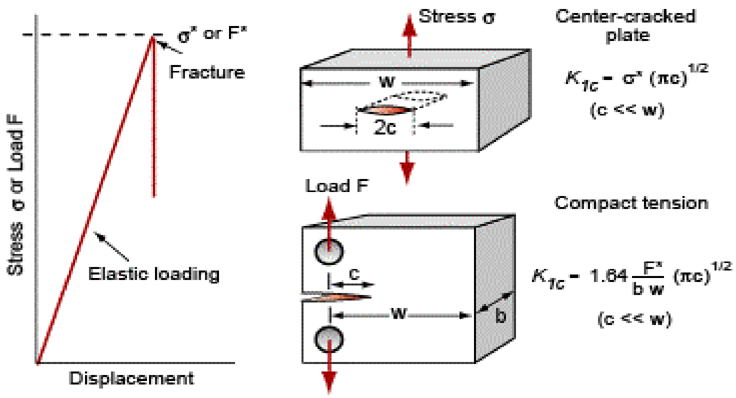

Fig.1:Measuring fracture toughness ,K_{Ic}

Y_1 and Y_2 are geometric factors, near unity, that depend on details on what are the details of sample geometry, E Young's modulus and b and w are thickness and depth of the beam, as shown in figure. This way of measuring K_{1C} can give the good values for brittle materials like ceramics, glasses, and some polymers. In case of ductile materials a small plastic zone is there at the crack tip. If this zone is small enough than the dimensions of sample than this K_{1c} remains valid, but if not then some complexities are there in measurement a complex characterization is needed. If the plastic zone is greater in size than the thickness of sample the crack does not propagate and sample yields before breaking.

Energy release rate G and toughness G_c.

New surface are formed on the fracture of material. Surfaces created possess energy, called surface energy γ, units Joules per square meter (typically $\gamma = 1$ J/m^2). A fracture sample across cross-section area A is 2A after fracture of two surface, which needs energy of least Joules for that$2A\gamma$.Here comes the question of necessary condition for fracture. It is external work required, or strain energy released to provide surface energy, γ per unit area, of the two newly created surfaces. Which can be expressed as

$$G \geq 2\gamma$$

Where G energy release-rate. Practically much more energy is required than 2γ because of plastic deformation at crack tip. Still the confusion persist: for a crack to propagate it requires energy G_c J/m^2 for creating two surfaces – a kind of "effective" surface energy, replacing 2γ. It is known as, the toughness or the critical strain energy release rate. G_c can be related to the fracture toughness K_{1c} in this way.

Let us think of a slab of some material of unit thickness stressed by. σ. Elastic energy stored in it

$$Uv=\frac{1}{2}\frac{\sigma^2}{E}$$

Per unit volume. Let crack length be c, as in Figure 2. The stress is released in semi cylinder of radius c radius. The energy contained:

$$U\ v=\frac{1}{2}\frac{\sigma^2}{E}\times\frac{1}{2}\pi c^2$$

Crack is extended by Δc, releasing the elastic energy. The energy spend for creating this two surfaces will cost is $G_C\Delta_C$. From previous equation, the condition for fracture

$$\Delta U=\frac{\sigma^2\pi c}{2E}\Delta c=G_C\Delta_C$$

But $\sigma^2\pi c$ is just$K1c^2$, so, taking Y= 1,

$$\frac{KIC^2}{2E}=G_c$$

when a crack extends.

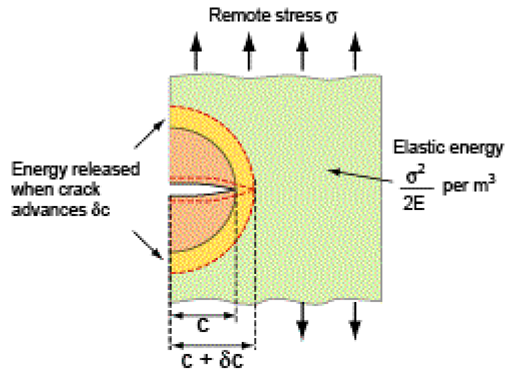

Fig2: Release of elastic energy

It is approximate eq. More complicated results shows that this equation is right up to some extent but is small by a factor of 2. Thus, correctly, the result we want (taking the square root) is:

$$K_{1c}=\sqrt{EG_c}$$

The origins of toughness.

A stress which is applied remotely stress applies a force which is transmitted by a cracked material as shown in Figure 3.Local stress, which is proportional to lines of force crossing unit length of area of cross-section the number of lines are greater on the plane having the crack in it due to less area, and it rises abruptly at crack tip approaches.

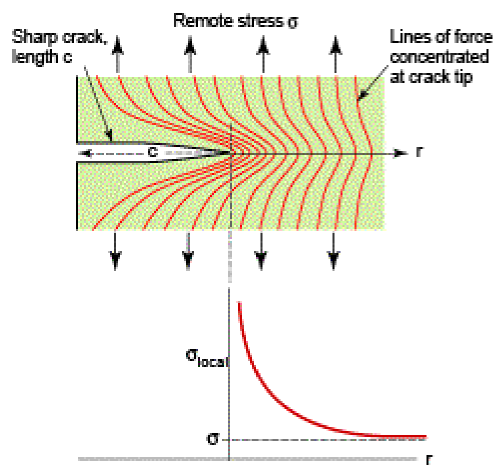

Fig.3: Lines of force in a cracked body

Under load

Stress field analysis of sharp crack suggest that the local stress at a distant r from its tip is

$\sigma_{local} = \sigma\,(1+Y\sqrt{\frac{\pi c}{2\pi r}})$

Near the tip stress rises at 1/√r.Glasses and ceramics have pretty high yield strengths, leave them with no way to relax this stress by plastic flow. That imply, near the tip stress reaches the critical strength. Which is enough to tear the atomic bonds apart, crack will spread, having its stress field with it, gives rise to cleavage fracture, as in Figure 4(a). Cleavage cracks travels very fast but has limited speed of sound in the material.

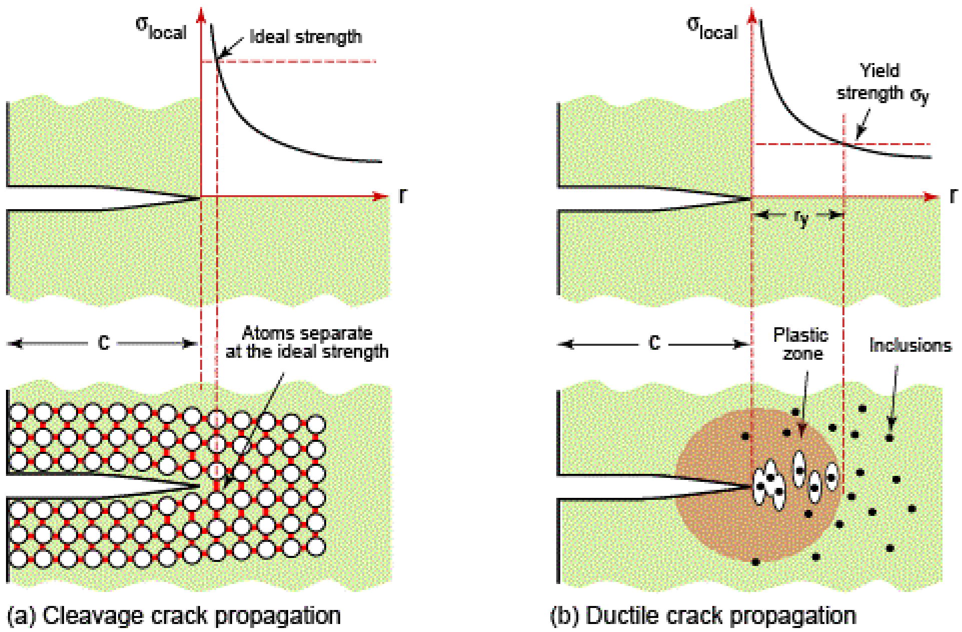

Fig 4 (a): Cleavage crack propagation   *Fig 4(b): Ductile crack propagation*

Ductile materials like metals and some polymers fracture is shown in (Figure 4(b)). The stress will rise as 1/√r more at the crack tip region, but as it exceeds the yield strength σ_y the material will yield, release the stress at that point other than some work hardening, the stress will not be more than this. The plastic zone radius is calculated by setting $\sigma_{local}=\sigma_y$

$$r_{y}=\frac{\sigma^2 c}{2\sigma y^2}$$

The size of the zone will shrinks very fast with increasing σ_y. Softer material have larger plastic zones but in ceramics and glasses have very small zones.

Very pure metals even have some tiny inclusions or particles, which can be formed as a result of reaction of the metal with impurities or oxygen. In plastic zone, plastic flow surround the inclusions which causes the debonding, results in elongated cavities that grow and further link to give a ductile fracture. Due to plasticity blunting of crack will be there & stress concentrating at blunt crack is less than a sharp crack, so further crack tip adjust itself such that the stress will be enough to keep material deform plastically there.

Cleavage fracture is most dangerous type of fracture, it occurs without any prior information or sign. Even some ductile metals and polymers shows brittle and cleavage fracture ,mode of switches to one of cleavage at low temperature ,only those metals which have fcc structure e.g.- copper, aluminum, nickel, and stainless steel ,remain ductile to the lower temperatures. While others have an increase in yield strengths at low temperature, as a result plastic zone becomes small up to that extant fracture mode switches, giving a ductile-to-brittle transition. It happens mostly in case of steel bridges, ships, and oil tankers are more likely to fail with climatic change from hot to cold. Even polymers show such type of transition

Fatigue

Failure due fatigue occurs when applied fluctuating stresses are significantly lower than the stress required for failure [1] when applied for single application. It has been seen that fatigue is the cause of failure for approximately 91% of service failures in mechanical components. Fatigue is there in every part or component which is moving. Fatigue as a problem was recognized in early 1800s when an investigation was carried on the cracks developed on bridge and railroad components when subjected to repeated loading. With the time metal usage increased with increase in use of machines, more failures were recorded due to repeated loads. Now, structural fatigue has become of greater importance because of use of high-strength materials and high performance desire.

Stress cycles

There are three things important for fatigue (1) Sufficient maximum tensile value of stress (2)variation in stress applied(3)High number of cycles of stress applied

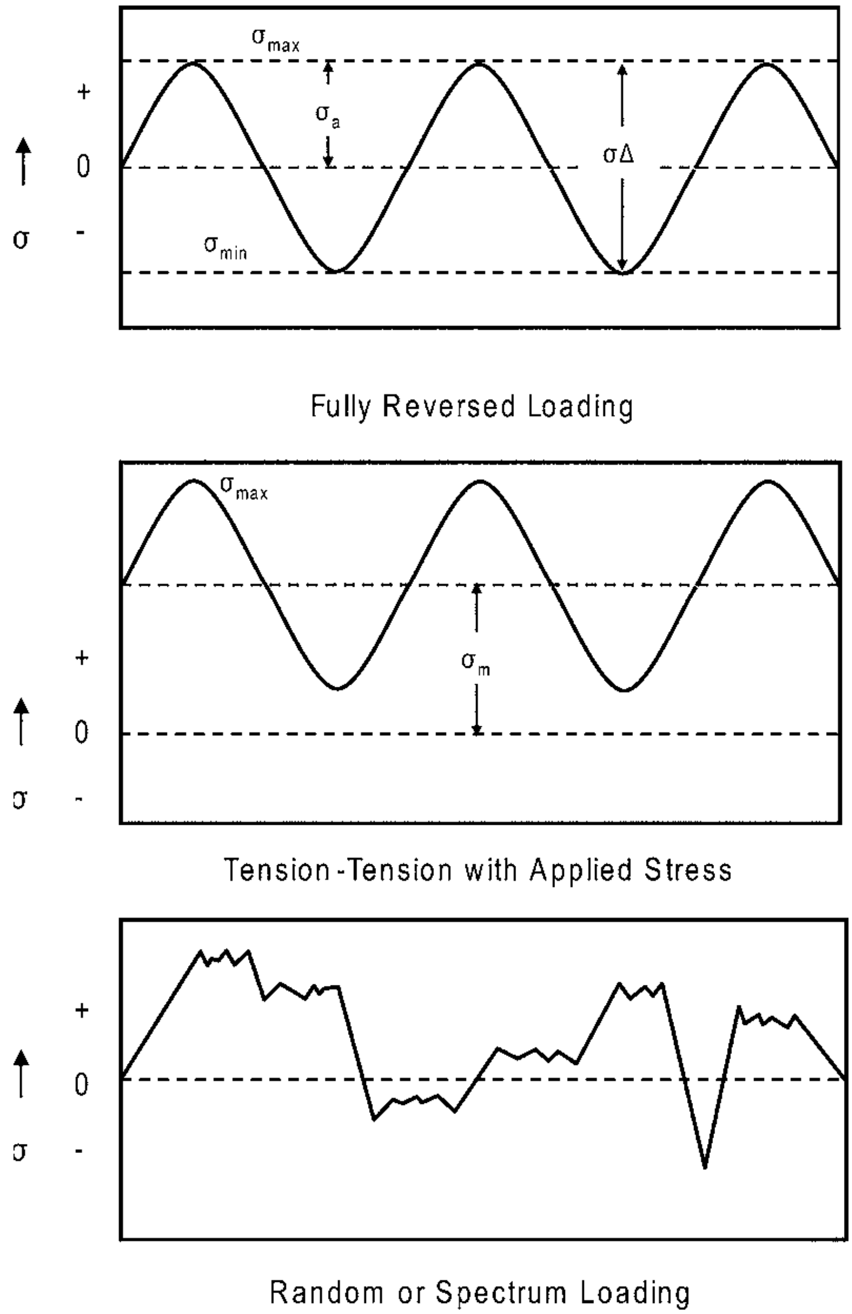

Fig 5. Typical loading cycles

Stresses of the more common types encountered are shown in Fig. 5. A completely reversed stress cycle as shown in graph of Fig. 5, where the maximum value and minimum value are same. Middle graph where both stresses are under tensile loading .It is also possible for both stresses in compression. Both values need not to be equal in value in two opposite loading directions. There could be random or irregular stress cycle, which is subjected to random loads during service, as in bottom graph of Fig. 5.There are such machines which are capable of tension and compression loading in both the high- and low-cycle fatigue test

A fluctuating stress is consist of two things: a mean or steady stress, σ_m, and an alternating or variable stress, σ_a. The stress range, σ_r, is the difference between the maximum and minimum stress in a cycle:

$$\Delta\sigma=\sigma_{max}-\sigma_{min}$$

The alternating stress is one-half the stress range:

$$\sigma_a=\Delta\frac{\sigma}{2}=\frac{\sigma\text{max}-\sigma\text{min}}{2}$$

The mean stress is the algebraic average of the maximum and minimum stress in the cycle:

$$\sigma_m=\frac{\sigma max+\sigma min}{2}$$

High cycle fatigue

In high-cycle fatigue large number of cycles are involved and stress is applied elastically. High-cycle fatigue tests are done for 10^4 to 5×10^8cycles in some nonferrous metals. Although stress applied is low in elastic range but plastic deformation takes place at crack tip. Plot of High-cycle fatigue data is usually presented by stress vs. N i.e. number of cycles to failure (log scale for N).

Stress value, S, can be the maximum stress, σ_{max}, the minimum stress, σ_{min}, or the stress amplitude, σ_a. S-N relationship determined usually for specific value of the two ratios, R or σ_m mean stress. The failure at a specified stress level at some number of cycle is known as fatigue life, whereas fatigue strength or endurance limit is the measure of minimum stress where less than failure does not occur. With the decrease of applied stress, number of cycles increases for failure. Generally, with increase in static tensile strength fatigue strength increases.

S-N curves for steel and aluminum is shown in Fig. 6. It is evident that steel has higher fatigue strength & endurance limit than aluminum.

A critical level reaches where the steel alloy does not fail alone due to cyclic loading .Whereas aluminum does not show any true endurance limit. It fail for a sufficient number of cycles. The fatigue strength of aluminum can survive at a large number of cycles up to 5×10^8cycles. There is good amount of scatter found in fatigue test results. It is advisable therefore to conduct sufficient tests for statistically meaningful results.

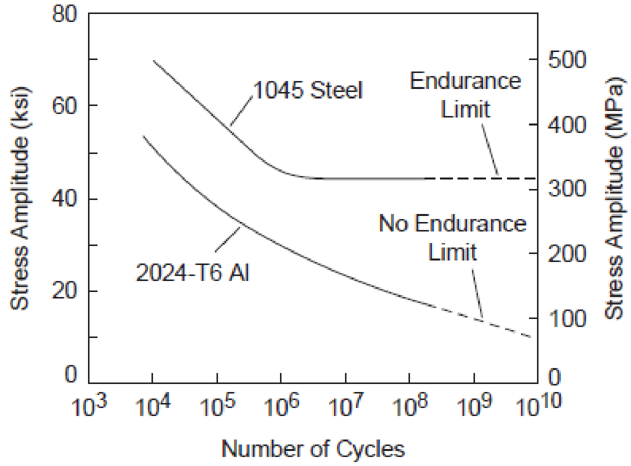

Fig 6: Comparison of aluminum and steel behavior

A small crack can result in fatigue cracking in quite early in service life of component generally at the external surface. Then crack propagation takes place in a direction perpendicular to the main tensile axis of the material. Finally, member fails due to insufficient cross section area of available material to take the load. The propagation is shown in Fig. 7 & fracture surface in Fig.8 of steel. The cracked portion due to overload & fatigue crack growth clearly evident.

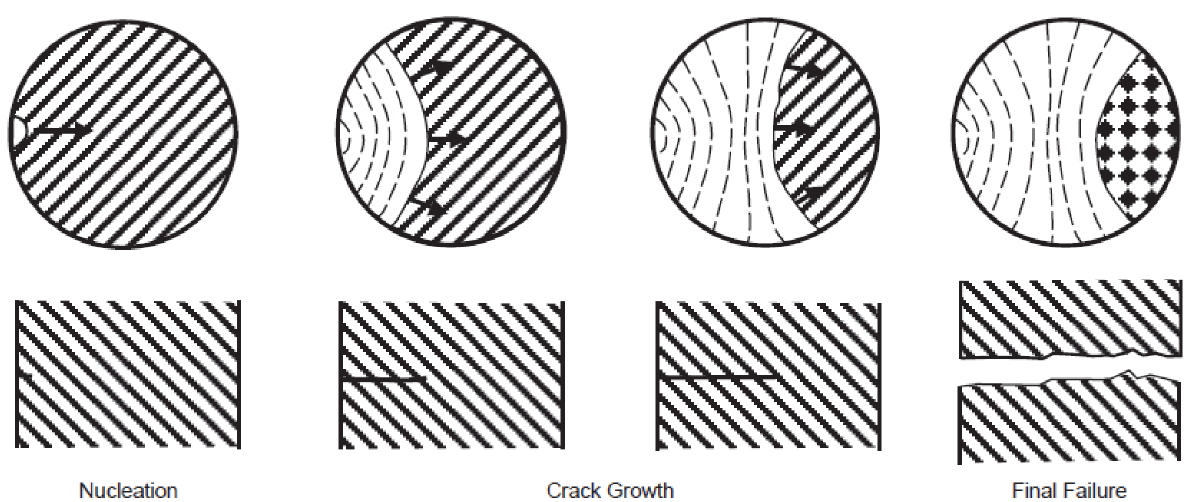

Fig7: Typical fatigue crack PROPAGATION

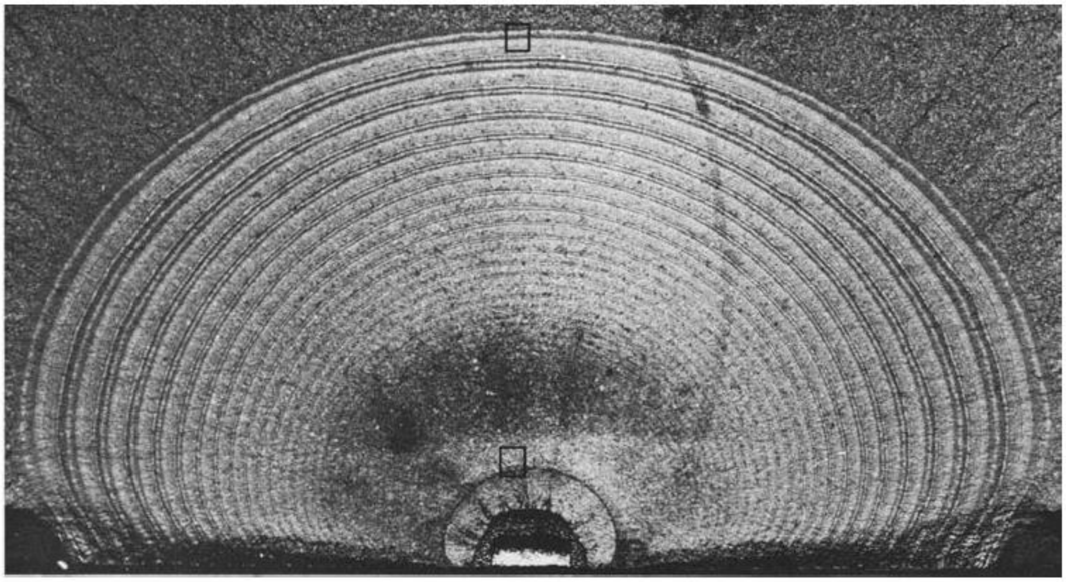

Fig 8: Fatigue crack growth in steel

Fatigue crack nucleation and growth

Initiation of fatigue cracks starts from the free surfaces, it starts from external surfaces provided the metal contains no defects such as voids or second-phase particles, else it initiates from internal surface. Defects of external surface include surface roughness and geometrical notches.

Fatigue crack nucleation and growth stages are as follow:

Stage I Notches or other surface discontinuity are the crack initiators. Even when there is no

surface defect, crack initiation occurs eventually due to persistent slip bands (PSBs) formation, it is called so because traces of these bands remains even after damaging or even after polishing the surface. Slip bands occurs due to systematic buildup of fine slip movements, on the order of only 1 nm. The plastic strain within the PSB are as much as 100 times more than the material in the vicinity. Due to back-and-forth movement of the slip band intrusions and extrusions are formed at the surface, which further leads to cracking, as shown in Fig.9. Initial crack propagates parallel to the slip bands. Initially crack propagation rate is low, the order of 1 nm per cycle, and the fractured surface produced is almost featureless.

The crack initially follows at 45° the slip band in the principal stress direction. When stress field become dominant at tip it happens when the crack length has increased sufficiently, the crack plane changes & it switches in the perpendicular direction of principal stress

Stage II When the stage I ends crack direction changes to the direction perpendicular to applied stress and propagates. A continual process of crack sharpening and blunting occurs as crack growth shown in the Fig. 10 . During crack propagation a pattern of fatigue striations is produced which is per cycle crack growth.

Striations indicates the fatigue, but fatigue failures can occur without striations formation also. Striations are examined with a scanning electron microscope, since these are not visible by naked eye, they are microstructural details.

Visual inspection of fatigued surface reveal a marking of series of concentric markings on the surface, referred to as beach marks .These are the result of stress changes during fatigue. Each beach marks contain thousands of thousands fatigue cycles.

Stage III. In final stage failure occurs when the fatigue crack becomes large and remaining cross section cannot withstand the applied load.

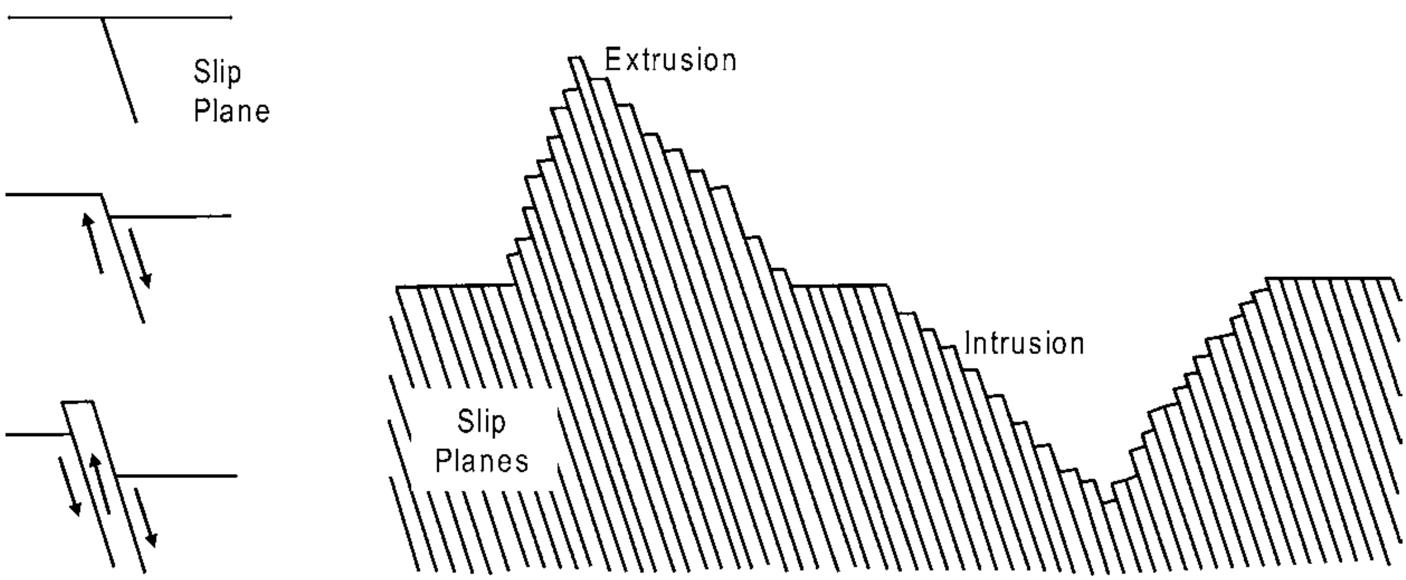

Fig 9: Development of extrusions and intrusions

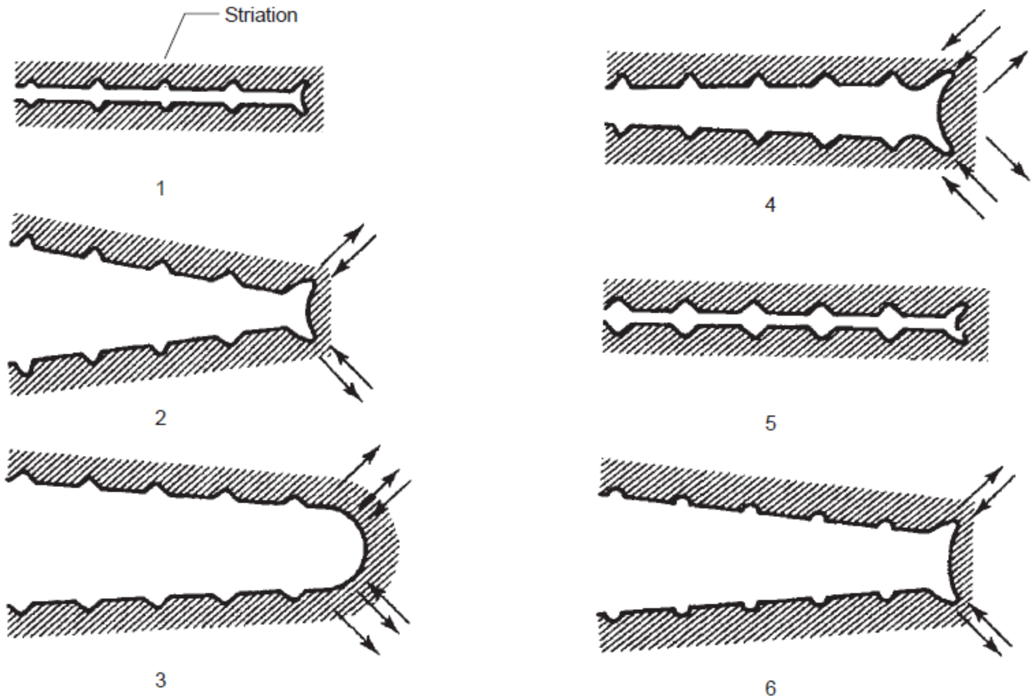

Fig 10: Fatigue crack propagation

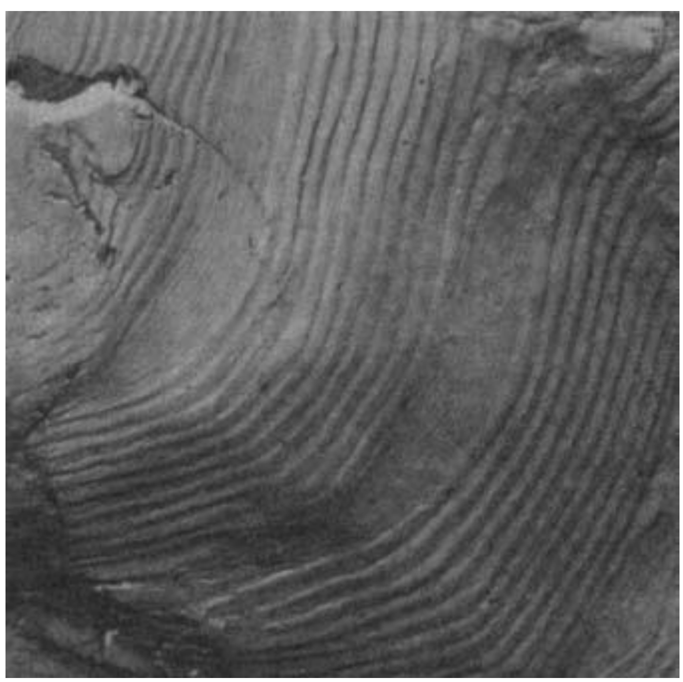

Fig 11: Striations

Fatigue crack propagation

According to linear elastic fracture mechanics all structures have flaws. Failure is the function of the number of load cycles and crack grows from a_0 initial size to $a_{c,}$ critical size as in Fig. 12. Crack growth rate, da/dN, is determined from the slope of the curve. Crack growth rate is slow initially but it increases with crack length. Crack growth rate is proportional to applied stresses. If characterization of crack growth is possible than estimation of service life is also possible, or, according to service environment, specific loading conditions and inspection at intervals are required. In the fracture mechanics when we talk about fatigue crack growth, or the crack growth rate, or the amount of crack extension per loading cycle, the stress-intensity parameter, K comes into the picture. This approach makes easier to estimate the safe lifetime and to establish inspection intervals. A da/dN versus ΔK curve is shown in Fig. 13. ΔK_{th} is the fatigue crack growth threshold, where crack growth rate is zero & ΔK is in lowest range called region 1, where crack growth rates is stable & linear can be expressed by the equation based on power law, known as Paris equation, in the region II. Such as the Paris equation:

$$da/dN=C(\Delta K)^m$$

where: a is the flaw or crack size in inches; n is the number of cycles; C and m are constant parameters and are related to material variables, environment, temperature, and fatigue stress conditions; and ΔK=ΔKmax_ΔKmin is the stress-intensity parameter range. The constants C and m are material parameters that must be determined experimentally.

We can determine the number of cycles to failure with the help of Paris law during stage II growth in the linear crack growth region, the Paris law can be used to determine the number of cycles to failure. ΔK can be expressed in terms of Δσ:

$$\Delta K=\Delta K_{max}-\Delta K_{min}=Y\sigma_{max}\times\sqrt{\pi a}-Y\sigma min\times\sqrt{}\pi a=Y\Delta\sigma\sqrt{}\pi a$$

Where Y depends on the specific specimen geometry.

Thus, the Paris law becomes:

$$da/dN=C(Y\Delta\sigma\sqrt{\pi a})^m$$

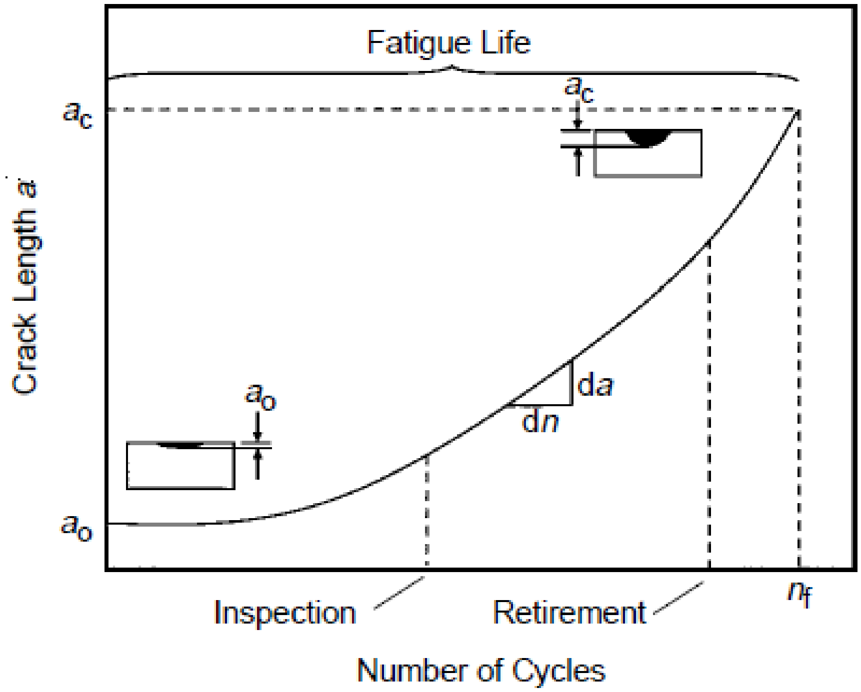

Fig 12: Crack length as function of cycle

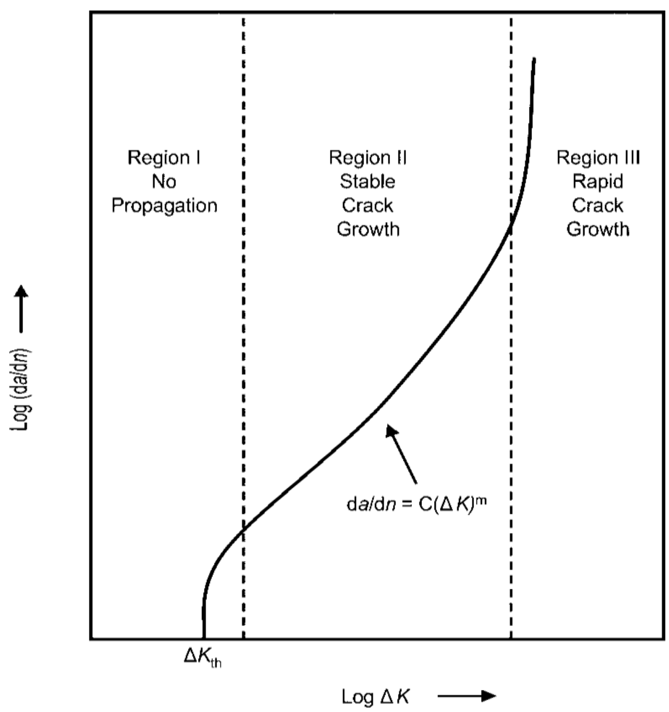

Fig 13: Crack propagation curve

1.2 Objective

The objective of the present work is as following

1. To conduct fatigue crack growth test at constant loading.
2. To conduct fatigue crack growth at various amplitude loading of single and 10 cycles of ORL 1.25
3. To conduct fatigue crack growth at various amplitude loading of single and 10 cycles of ORL 1.5
4. To conduct fatigue crack growth at various amplitude loading of single and 10 cycles of ORL 1.75
5. To study the overloading effect on the cases as described above.

Chapter 2

Literature review

2.1 Literature on fatigue and fracture

There are two-parameter responsible for cracking during fatigue crack growth , ΔK vs. K_{max} are related by power-law relationship, according to [2].Crack propagation region are of two types ΔK and K_{max} dominated, for respective high and low load ratios. Transition from ΔK and K_{max} dominated happens at ratio from 0 to 0.5.If we plot the slope of ΔK vs. K_{max} then actual slope is more than the theoretical one for K_{max}. CP table is effective procedure for prediction fatigue crack growth rate.

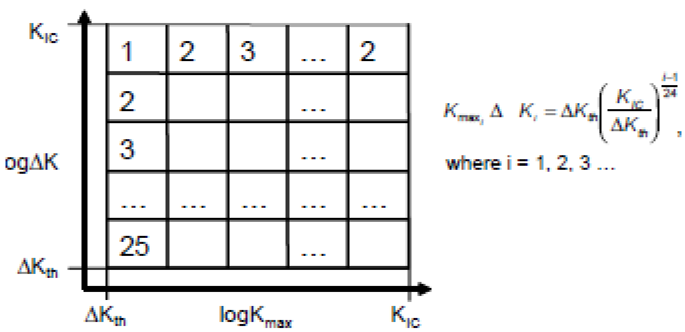

Fig 14: Crack propagation table

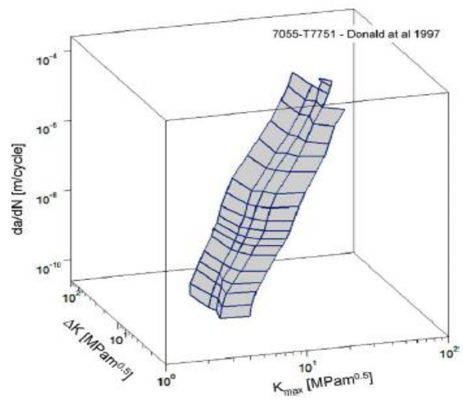

Fig 15: Crack propagation table for Aluminum sample 7055

Now for crack growth both K_{max} and ΔK should be more than threshold values then $K_{max}*$ and $\Delta K*$ are critical values for crack growth. Variation of $K*$ vs. $Kmax*$ gives trajectory map as crack growth rate its function [3], shown in Fig .16, at $K* = Kmax*$ cyclic strains induce pure fatigue crack growth behavior. The trajectory maps of these steels show deviations due to superimposed environmental effects. These are effected by grain size, microstructure, and yield strength.

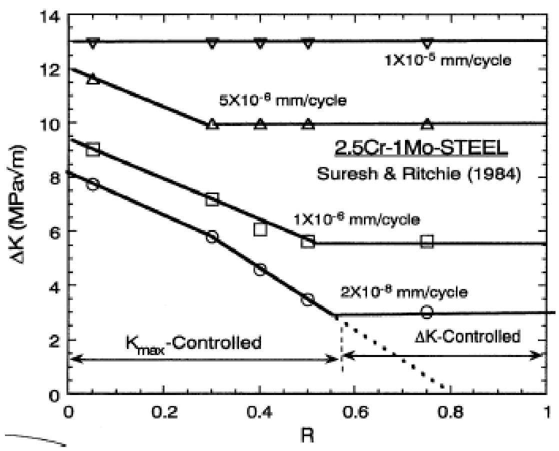

Fig16: ΔK-R plots for a low alloys steel at various crack growth rate

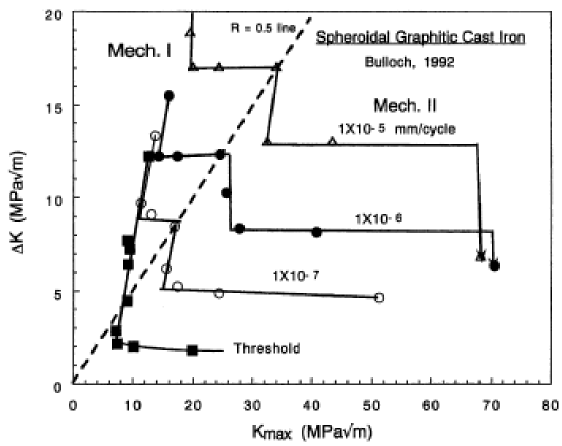

Fig17: ΔK–Kmax plots for spheroidal graphitic cast iron showing two mechanisms

Operating as a function of R

Generally in the Paris regime microstructure does not affect crack growth rate. Mechanical similarity is there when we plot the curve between FCG and ΔKeff, effective stress intensity factor, in fact most aluminum alloys behave in the same manner. But according to [4] various aluminum alloys series varies 20 of the factor at upper nominal stress intensity factor range, which suggest crack closure is affected by material type.

Age hardening alloys like 7××× series have weak grain boundary regions because grain boundary are coarser formed when quenched & have very less precipitates in that zone[5].Moreover in interior part of grains primary particles are present which favors void nucleation, growth and its coalescence leads to crack formation. Crack initiation will be outcome of the competition between inter granular fracture along grain boundaries at weak areas and Trans granular type of fracture at intermetallic particles void formation within grains. Grains are elongated in rolling direction fracture depends on orientation of grain boundaries and stress applied direction.

In order to predict fatigue life an approach of critical plane is useful and plane of crack initiation too[6].In Fig. 18, fatigue distribution per cycle over a plane orientation is shown for loading condition. A 10% range of maximum fatigue is taken for prediction of fatigue. Maximum points are predicted critical planes and cracks are form on these planes only, theoretically.

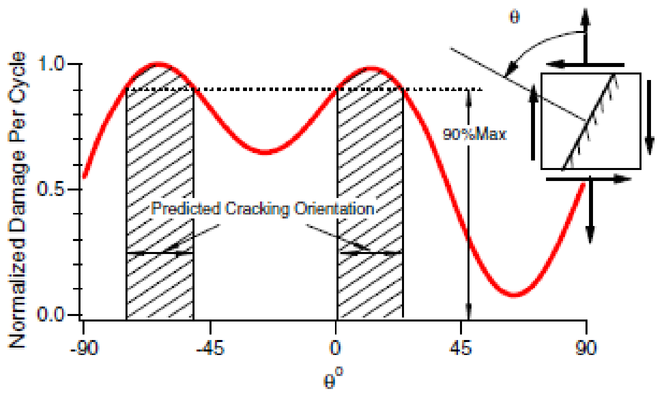

Fig 18: Dependence of fatigue damage on material plane orientation

R-ratio and material dependence of fatigue is related to different closure [7]. Here roughness-induced is prime closure mechanism retardation of crack seems due to this only.

2.2 Literature on overloading

In II stage, tensile overloads may give positive response in terms of fatigue life. While overloading a high crack-tip strain is there results in a plastic deformation region which is quite large ahead of crack. Due to this volumetric plastic expansion takes place which tries to close the crack. The subsequent to that will have to overcome first the compression residual stress

. This result in crack growth retardation. As shown in Figure 19. Retardation. Continues till it propagates through the pre compressive zone effectively. In such condition a full crack arrest can take place where the small cycles cannot ever overcome compressive residual stress. In order to have a good understanding of it, let us take an example: When you notice a crack in an airliner's wing, pilot is instructed to roll aircraft for crack arrest to take place .It is because if UTS is exceeded there are more issues to get concerned rather than fatigue . It is not necessary that overloading is always beneficial for crack retardation at some points it has been observed overloading has caused massive damage too.

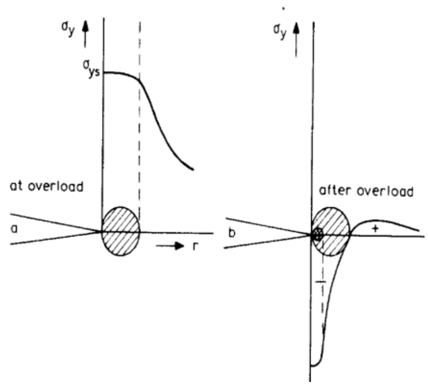

Fig 19:A residual compressive zone due to overloading

As we have just discussed residual stress is responsible for crack growth retardation rather than crack closure. Residual stress have no effect on cyclic amplitude but affect K_{max}, K_{max}

is a driving force of fatigue crack growth [8].In this study they involve $\Delta K–K_{max}$ crack growth prediction this includes two driving force and two threshold.

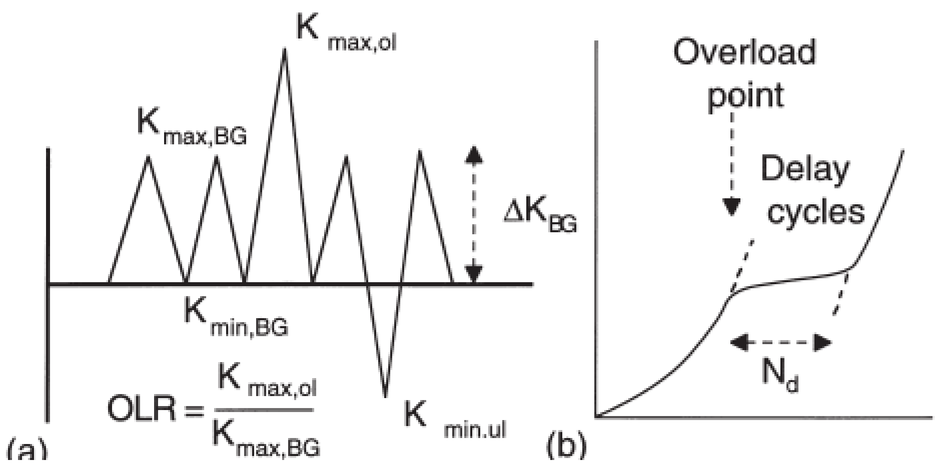

Fig 20: overloading effect on fatigue crack propagation

Another model fatigue crack propagation process during overloading was proposed[9] .Which tells three factors affect the crack growth rate ; the crack growth resistance of the material increases due to blunting of crack tip ;residual stress field which affect threshold in the process zone of micro damage accumulation, change of properties at microstructural level at newly blunted crack tip.

Effect of OLR and baseline ΔK level was observed in overloading .The retardation of crack increase with OLR and ΔK_{BL}, and with decreasing R [10].The transient region region length is affected by loading variables also, OLR seems influential on type of ΔK at baseline and its effect on the retardation. Moreover crack closure is affected by loading parameters. A crack can be remained opened permanently after overload application [10].Asperities induced closure is dominant immediately after overloading [11].

In some of the studies [12] it was found single cycle overload can decrease the life compared to no load situation, basically depends on the starting of overloading cycles & type of loading parameters.

The effect of periodicity is also noticed on the overloads [13], for e.g.: number of overload cycles & constant amplitude cycle between two overloads & the overloading ratios is also noted.

Planer slip behavior offers delay after overload [14] .Delay is significantly high in vacuum, environmental effect is prominent in delay which can be explained using plastic zone model. It also depends upon micro mechanism of fatigue. By computational study a new mechanism of retardation is proposed [15] for transient behavior just after overload, as found in initial cycles of loading. For many of the cycles after overloading crack closure doesn't occur at crack tip even at minimum load in every cycle, but after this period of transition closure starts to occur once again & gradually crack growth is stopped completely. In some studies [16] it is shown that there is no effect of overloading in fatigue crack initiation but the interaction of load between load spectrum& load sequence matters.

Now in the case of single overload there is a crack acceleration initially followed by retardation just after overloading cycle when single overload is applied, but in case of multiple overloads [17] depends on the interaction of one overloading cycle with the following overloading cycles depending upon the frequency of the overloading cycles. Furthermore, the crack growth retardation is reduced during the latter stage of the fatigue life of a structure when the net section stress approaches the yield strength of the material. More will be the interaction spacing between the loads more will be retardation but it is limited up to a point of decrement of spacing.

Assuming plastic zone toughening for ductile, materials, a plastic –corrected stress intensity factor is introduced to explain the overloading effect [18].It not only tells the effect of overloading but also load ratio, loading variables, load ratio, overload extent and overload number, overload retardation. The greater retardation can be achieved by higher over loading ratio [19].

A compressive region of residual stress is found in front & back of crack tip just after the overloading[20].effective stress intensity can be found at crack tip from load stress field within bulk measured by comparing with LEFM.

According to J.schijve [21] fractography is one of the best way for studying the overloading or variable load effects. Which tells plane stress zone or surface region is major reason for retardation of crack. Shear lip effect, residual compressive stress, strain hardening plays the key role in retardation along with crack closure [22].Closely spaced overloading accelerates the crack growth, whereas remotely applied overload does not affect each other. Overloads retards the crack growth rate ,while under loads accelerates crack growth, these sort of interactions depends highly on loading sequence, making prediction of fatigue life much more complicated .There are many models developed for this variable amplitude loading[23-24].Most popular among them is wheeler model[25] based on yield zone size at tip of the crack.

Some models are based on crack closure, which takes in account, the wake or plastic zone & crack face [26].Some models are based on density factor [27].But due to complex and complicated mechanism involved in it, drastic change is there in variables. This area invites a lot of researchers due to such complexities.

Chapter 3

Experimental

3.1 Material & Specimen

Test was conducted at room temperature and air on the material 7075-T651a heat treatable Al-Zn-Mn precipitation hardening alloy .Composition of alloy is given in table 1.The cyclic test was conducted on a servo hydraulic machine of 100 kN. The load was calculated according to the ASTM E-647.

Table 1: Composition of alloy

Aluminum	Zinc	Magnesium	Copper	Chromium	Iron	Silicon	Titanium	Manganese	Others
89.6%	6%	2.4%	1.4%	0.18%	0.16%	0.04%	0.05%	0.02%	0.15%

Mechanical properties due to such composition and thermo-mechanical treatment is as follows:

Table 2: Mechanical properties of alloy

Tensile strength (MPa)	Yield strength (MPa)	Elongation %	Hardness VHN	Fracture toughness K_{Ic} (MPa-√m)
598	557	13	170	26

A CT (compact tension) specimen of 12.6 mm thickness was used for fatigue test. Specimen orientation was L-T for experiment and loading was done parallel to loading direction, notch length was kept 9.5mm and width of specimen was 50 mm, with 10 mm knife edge gauge length and 12.7 mm pin hole diameter.

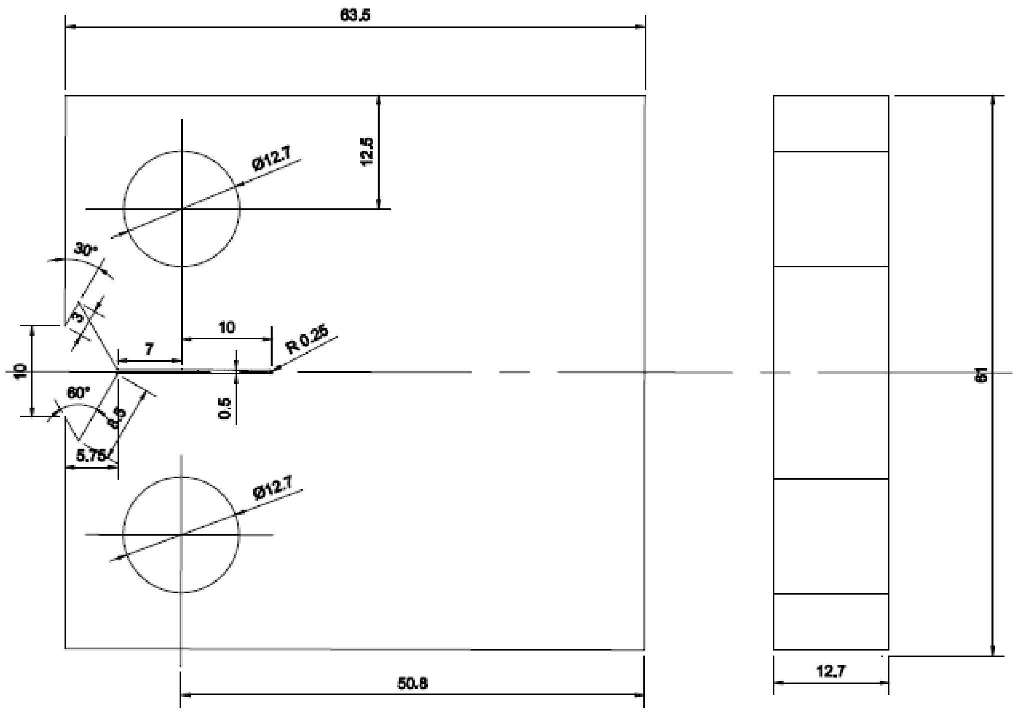

Fig 21: Geometry of CT specimen

3.2 Experimental Procedure

Experiments were carried out on BiSS-ITW machine having load cell capacity of 100 kN, setup of test is as shown in Fig 22. .Specimen surface were polished & a graph paper was stick to the sample for cross checking the crack length manually, measured by the machine. Test were carried out at P_{max}=4 kN and P_{min}=1.19 kN on the frequency of 12 Hz.

Crack measurement was done According to ASTM standard with the help of COD gauge, COD was mounted on centerline with the help of knife- edges.

Fig 22: Test setup

Test was carried in following sequence.

Specimen was mounted on the machine with the help of pins, after calibrating the load cell & COD, test was conducted for constant load, single overload and multiple overloading cycles for Mode I loading.

Following equation was used for determining stress intensity factor [30].

$\Delta K = \Delta P / B\sqrt{w} \times f\,(a/w)$

Where

$f\,(a/w) = [(2+a/w)/(1-a/w)^{\frac{3}{2}}][0.886+4.64(a/w)-13.32(a/w)^2+14.72(a/w)^3-5.6(a/w)^4]$

The test was conducted at 12 Hz frequency, constant amplitude, at stress ratio R=0.3 and constant load mode starting from ΔK=4 and load 3.97kN calculated.

When crack reached at second region of Paris curve, in this experiment a=17.5,a/w=0.35 overloading was done at 1.25 OLR, 1.5 OLR, 1.75 OLR for single cycle overload and 10 cycles overload for every overloading ratio.

After application of overload, constant load was carried, up to the crack length of 34mm where it reaches the region 3 of Paris curve.

Chapter 4

Result & Discussion

The microstructure of material inT651 tempered condition was developed and presented in Fig.23

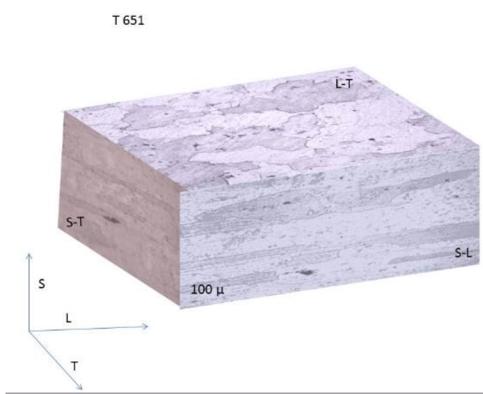

Fig 23: Microstructure of AA7075- T651 alloy

4.1 Constant amplitude fatigue test

Constant amplitude fatigue test of material was conducted at stress ratio, R=0.3 at initial stress intensity parameter range ΔK=4 MPa-$m^{\frac{1}{2}}$ at constant load condition, crack length a=9.5 and corresponding maximum load P_{max}=3.987 and at frequency 12 Hz. Crack growth vs. Number of cycle plot is given in Fig. 25.Crack growth rate vs. stress intensity factor range plot is given in Fig.26.

4.2 Overloading results

The experimental results of fatigue crack propagation on application of overloading cycle was done at different overloading ratios 1.25, 1.5, 1.75 respectively at the same crack length 17.5mm at corresponding Δ K =6.2 MPa -$m^{\frac{1}{2}}$ and further cracked up to 34mm.Overloading was done for single cycle and 10 cycles, during overloading frequency was kept 0.125 Hz. Data used for analysis of overloading are a vs. N plot which do not show any significant growth for any of the loading condition.

Fatigue crack growth rate and stress intensity parameter range plot is used for clarity for every loading condition and overloading loading cycles, fatigue crack growth rate and crack length plot is used for analysis every specimen.

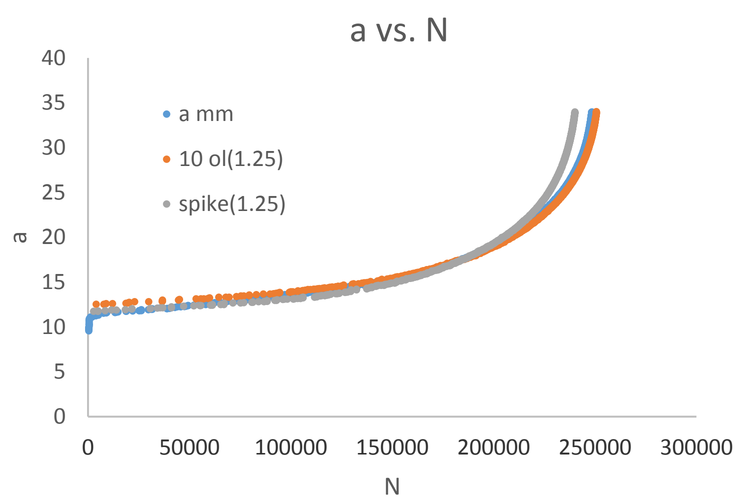

Fig 25: a vs. N plot for 1.25 ORL

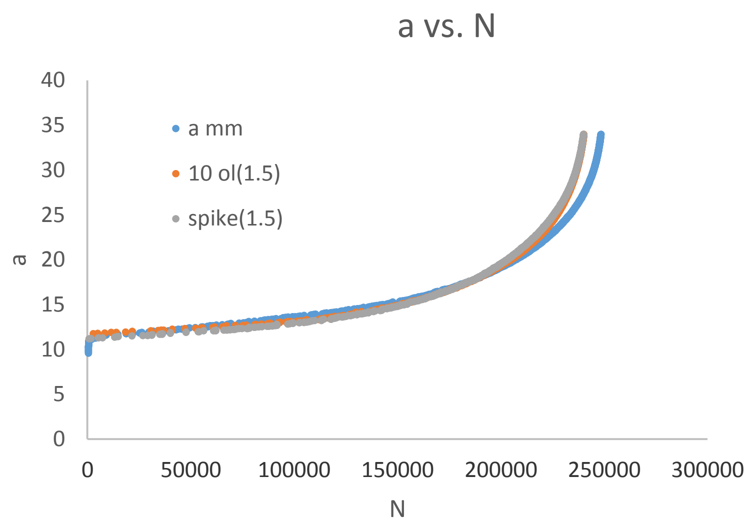

Fig 26:a vs. N plot for 1.5 ORL

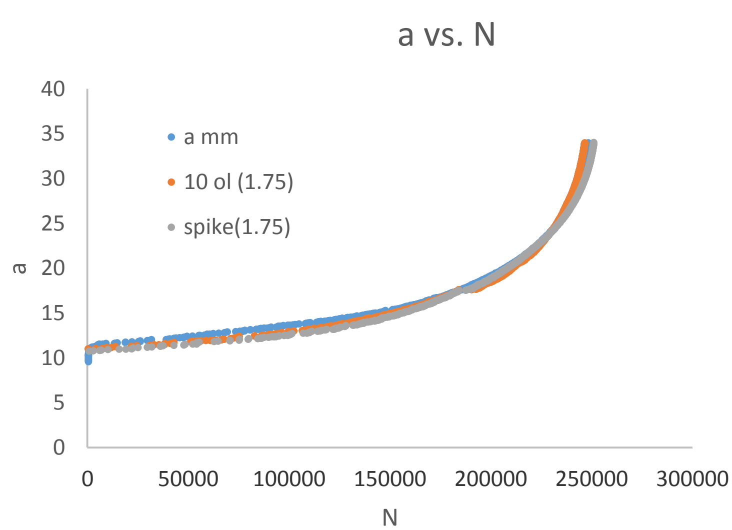

Fig 27: a vs. N plot for 1.75 ORL

The above curves do indicate the extension of crack on application of stress cycles. However the retardation expected on overload application cannot be visualized. The above crack growth data are subsequently presented in the form of da/dN vs. ΔK plot. The plots indicate no significant retardation on application of single overloading of OLR=1.25. No significant retardation was also observed on application of single cycle of OLR=1.5. However, the introduction of single cycle of overload of OLR=1.75 resulted some retardation in crack growth. These behavior of crack growth can be visualized in Figs. 28-30. The effect of band overloading (OLR= 1.25, 1.5 and 1.750 can be visualized in Figs. 28-30.However only band overloading with OLR 1.75 shows some sign of retardation on crack growth .The crack growth rate are presented as a function of crack length *a* in Fig.31-33.No retardation was observed in case of OLR=1.25 single overload, no retardation was observed in case of 1.5 single overload. No retardation was observed in case of OLR=1.25 10 overloading cycle. Significant retardation was observed ORL=1.5 for 10 overloading cycles, and ORL=1.75 for single and 10 overloading cycles. Maximum retardation was noticed in case of OLR=1.75 and 10 number of overloading cycles.

Insignificant retardation in case of OLR=1.25 may be due to low value of maximum stress at the notch tip and corresponding stress intensity factors ΔK(6.14) and K_{max}(6.822). This has resulted monotonic plastic zone size not large enough to retard growing crack. On the other hand the higher value of overloading ratio (OLR=1.75) induced large monotonic plastic zone and therefore the significant retardation. The application of band overload, on the other hand, developed a series of monotonic plastic zone, identical to plastic wake

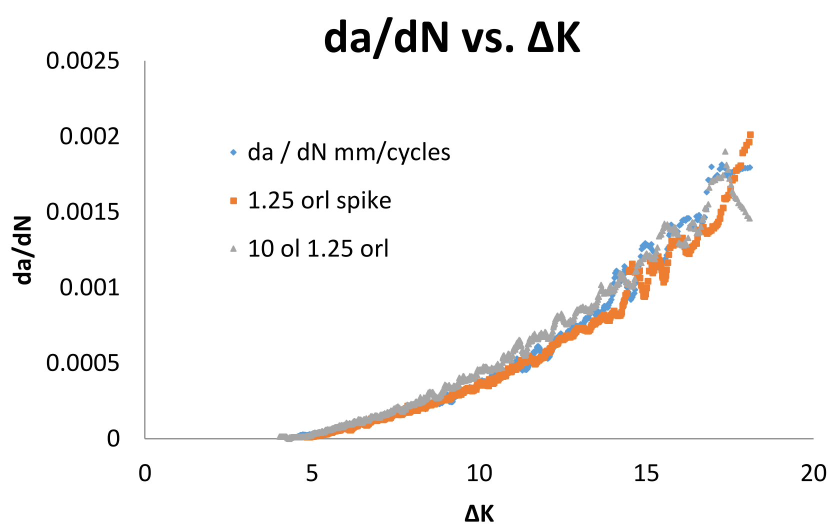

Fig28:da/dN vs. ΔK plot for ORL 1.25

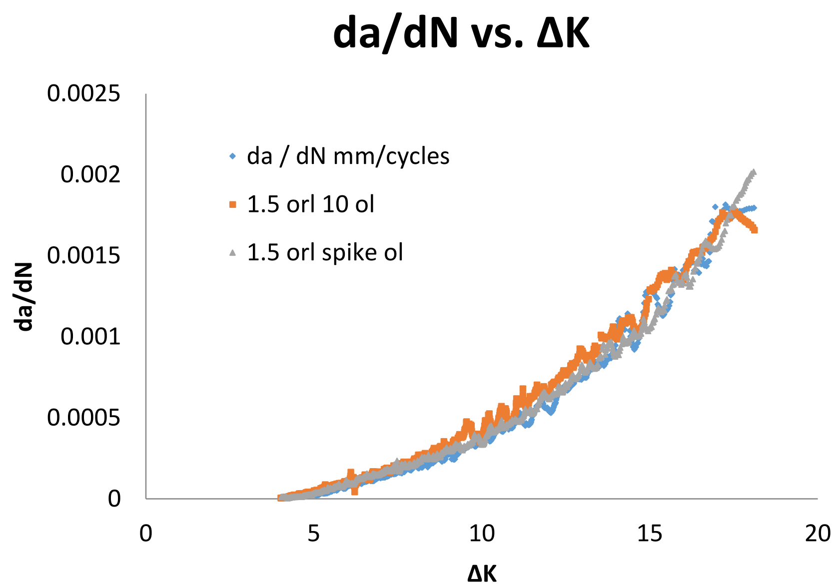

Fig29: da/dN vs. ΔK plot for ORL 1.5

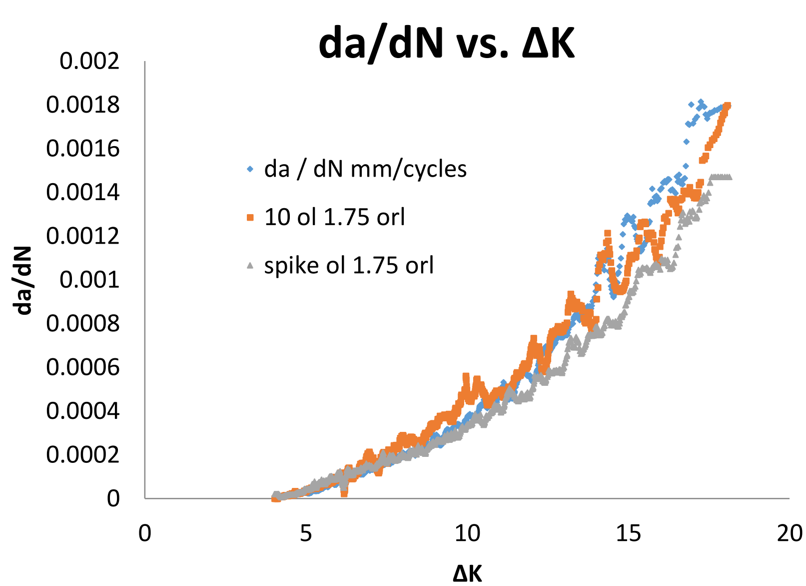

Fig 30:da/dN vs. ΔK plot for ORL 1.75

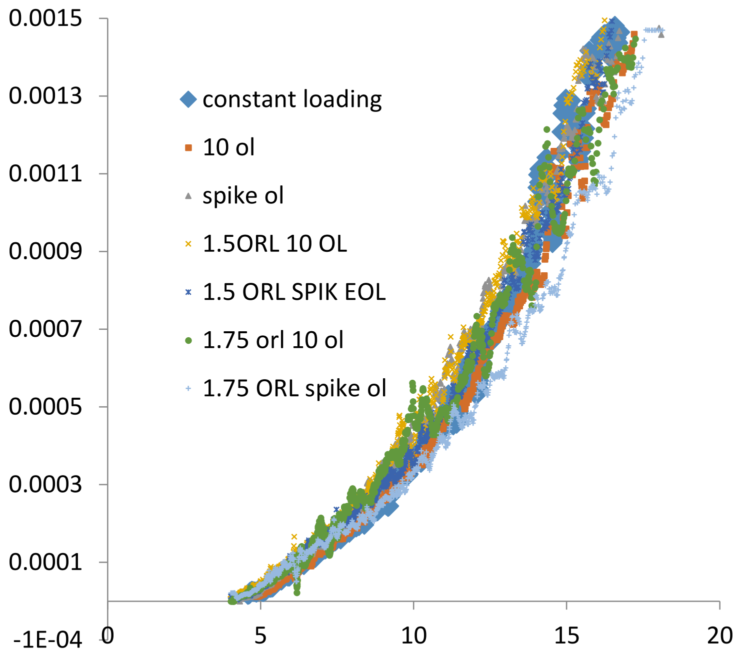

Fig 31:da/dN vs.ΔK plot for all ORL and overloading cycles

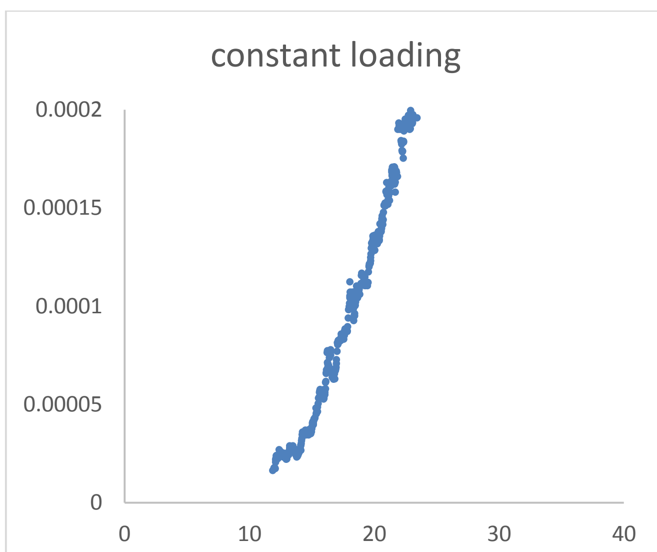

Fig 32 (a):da/dN vs .a plot for constant loading cycles

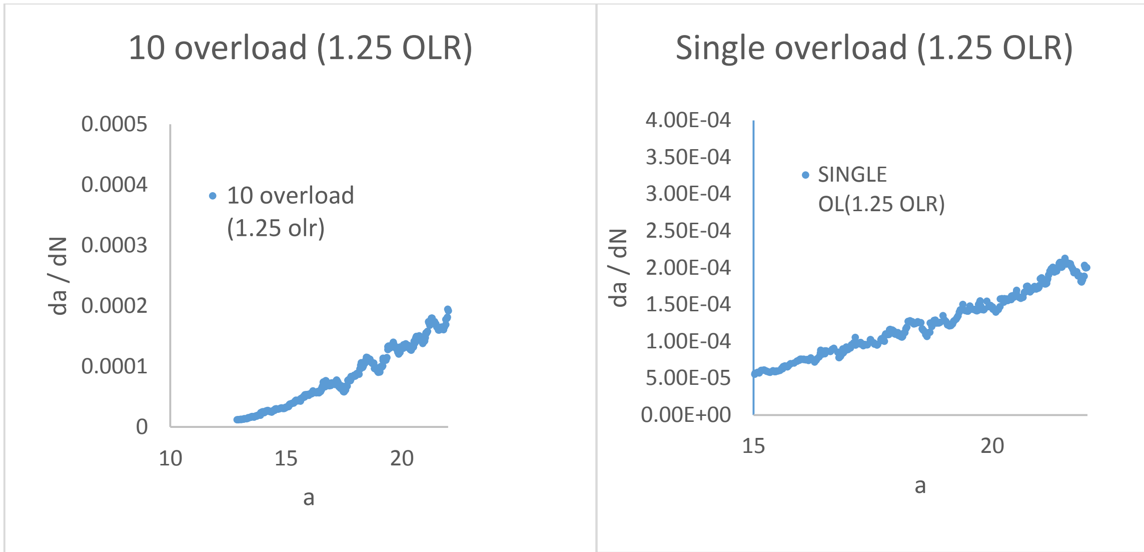

Fig32 (b):da/dN vs. a plot for ORL 1.25

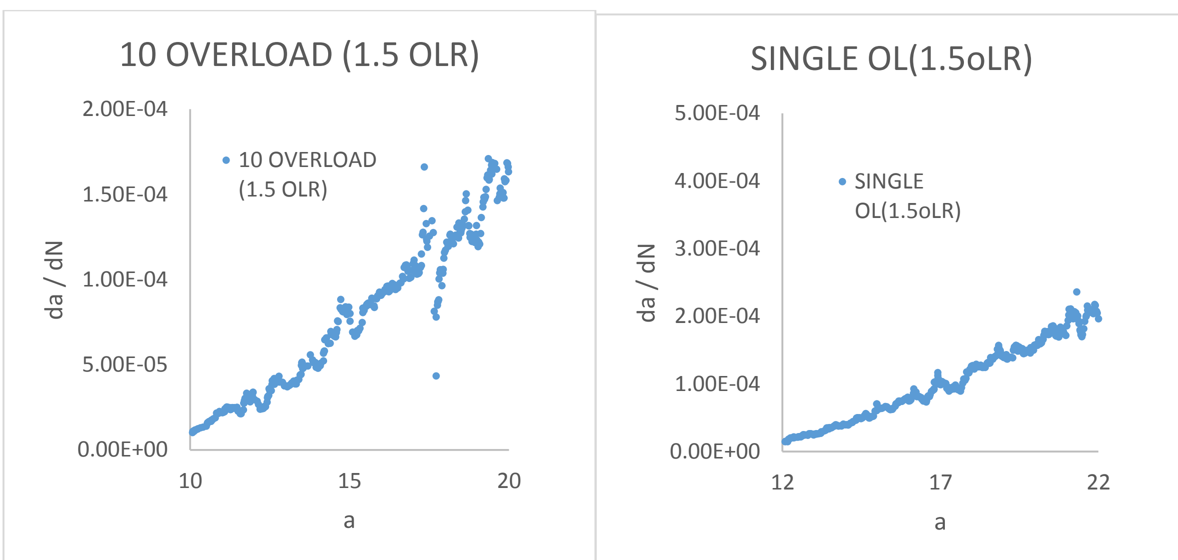

Fig 33:da/dN vs. a plot for ORL 1.5

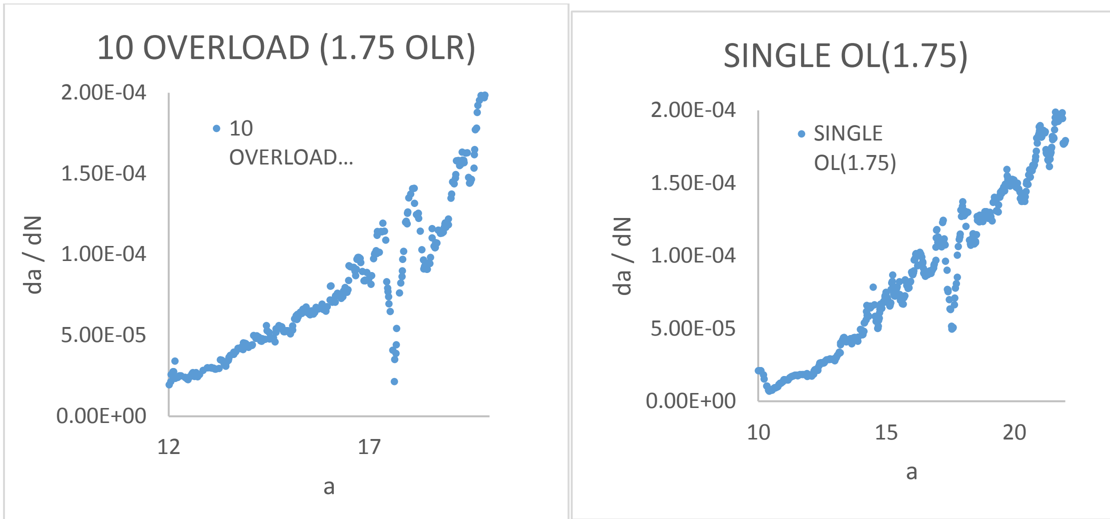

Fig 34: da/dN vs.a plot for ORL 1.75

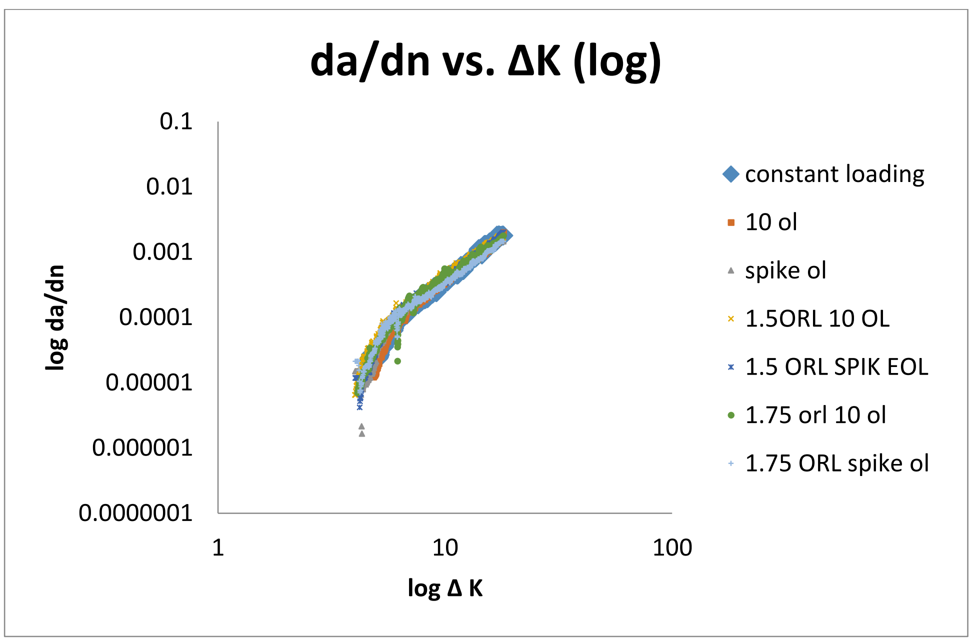

Fig. 35:da/dN vs. ΔK plot on log scale

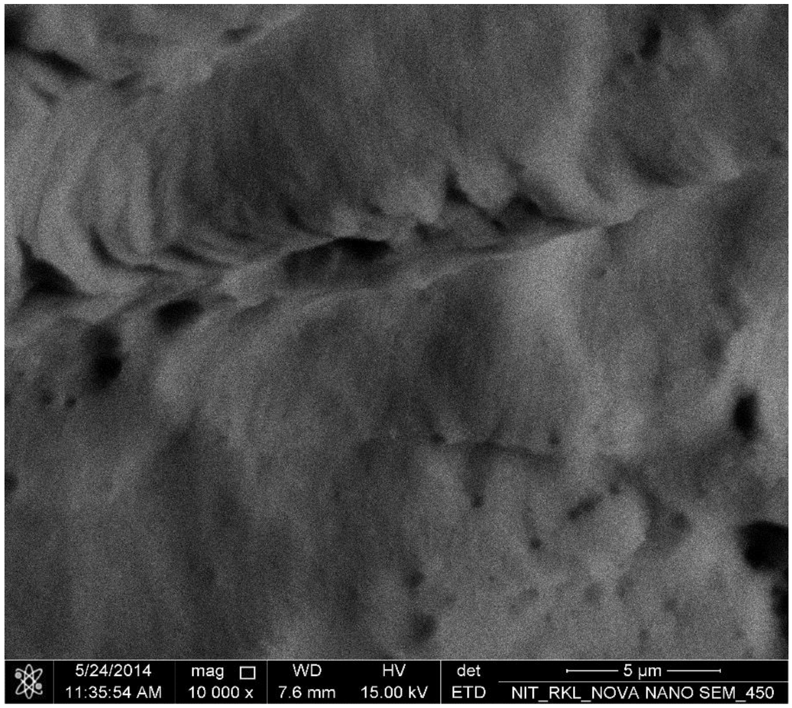

Fig. 36: Ductile fatigue striations in constant loading test

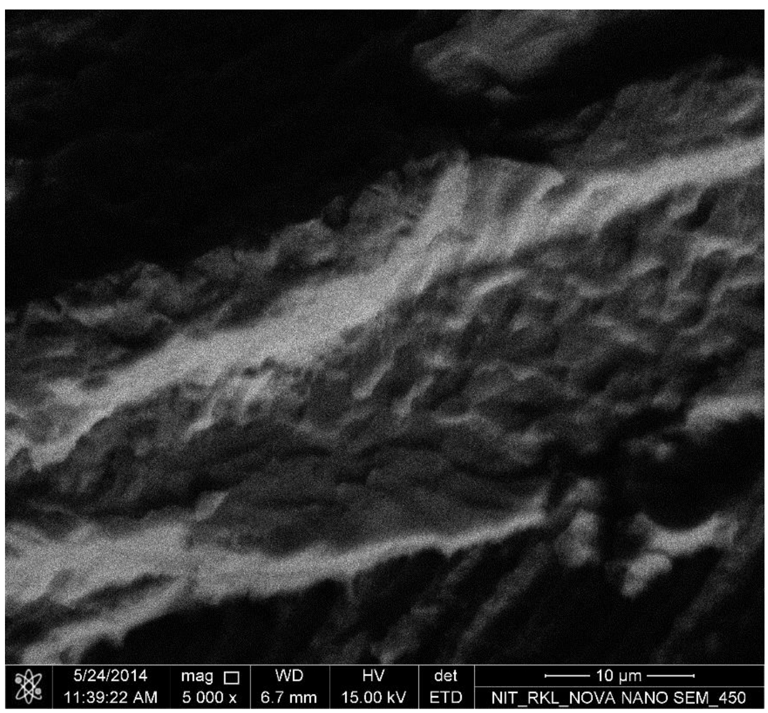

Fig.37:SEM Fractography after 10 cycle at OLR 1.25

Chapter 5

Conclusion

Fatigue crack growth test under loading condition of single overload and 10 overload cycles for subsequent OLR=1.25, 1.5, and 1.75, showed the following effect:

[1] Single overloading cycle for OLR =1.25 does not show any sign of retardation in fatigue crack growth rate.
[2] Band overloading cycles for OLR=1.25 does not show any sign of retardation in fatigue crack growth rate. This may be due to low level of overload.
[3] No retardation was observed for single overloading cycle at ORL=1.5
[4] Retardation was observed for all overloading conditions (both single and band overloading) at ORL=1.75.
[5] An increase in retardation of crack growth rate is noticed with increasing level of overload.
[6] Insignificant retardation is the result of small monotonic plastic zone, whereas at higher OLRs create large monotonic plastic zone large enough to retard a growing crack.

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